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Performance Studies of TCR on Transient Stability

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ABSTRACT
Static VAR compensators including thyristor controlled reactor (TCR) which are employed for compensation are nonlinear elements. Nonlinear components linked to power systems distort the current and voltage waveforms, therefore harmonic components are occurred. These harmonic components cause some resonance events in the system. As a result of resonance functions, the system might be instable. In this article, both harmonic production and operating values in nonsinusoidal situation are examined for different functioning conditions.

Keywords
Thyristor Controlled Reactor (TCR), Stability, Harmonic, Voltage, active power.

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1. Introduction
Power system designers are still facing problems to improve the power transfer convenience of present indication systems. Flexible-AC-Transmission-Systems (FACTS)-controllers provide an economical answer to support that require while maintaining adequate steady-state and transient stability margins. Because of fast and flexible actions of FACTS devices, many relevant benefits can be achieved such as for instance usage of transmission ability, effective power-flow control, transient stability development, power oscillation damping, subsynchronous resonances mitigation, and fault current issue [1].

Recently, resources have already been enthusiastic about using static VAR compensators including TCR technology on distribution systems [2]. Furthermore, the power factor could be improved simultaneously by selecting a suitable amount of capacitive/inductive compensation [3].

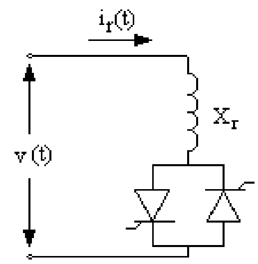

Figure 1. The main components of a TCR

There are many well-known sources of harmonics contained in AC power systems. These generally include AC/DC converters, transformer saturation, arc furnaces, etc. Still another supply of harmonics that will be increasingly being used in power systems, but, may be the thyristor controlled reactor (TCR) which is gaining popularity as a technique of voltage control [4]. However, as the TCRs contain power electronic components, harmonics and their impacts on the system should be studied [5]. The fundamental elements of a TCR certainly are a reactor in series with a bi-directional thyristor as revealed in Figure 1.

2. Thyristor Controlled Reactor (TCR)
Thyristor controlled reactors, which may the capability to assure a continuous and rapidly reactive power and voltage control can increase the efficiency of the system from various ways: Such as control of transient over voltages at power frequency, preventing of voltage collapse, increase in transient stability and reduction in the system oscillations. Static VAR compensators consist of thyristor controlled reactors are employed for balancing the

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three phase systems supplying unbalanced loads and for avoiding the voltage oscillations caused by small period loads in transmission and distribution systems.

To be able to create a more correct in frequency model, the circuit in Figure 2 is analyzed. This presents a fixed capacitor-TCR static VAR compensator linked to an AC system constructed as a system reactance, X_s, a voltage source, v(t). The two parallel thyristors are gated symmetrically. They control the time for which the reactor conducts and hence control the basic component of the current [6].

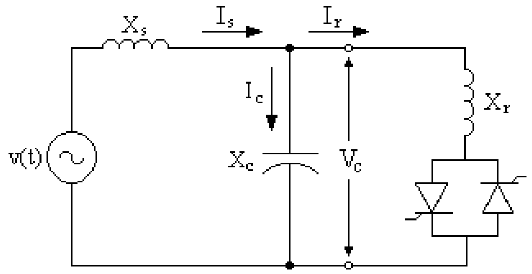

Figure 2. Fixed capacitor-thyristor controlled reactor static VAR compensator.

The thyristors conduct on alternate half-cycles of the source frequency with respect to the firing angle α, that will be assessed from the zero crossing of voltage. Complete conduction is acquired with a firing angle of 90°. The current is basically reactive and sinusoidal. Partial conduction is received with firing angles between 90° and 180°. Firing angles between 0 and 90° are not allowed because the create asymmetrical currents with a dc component. Let σ be the conduction angle, linked to α by

$$\sigma = 2(\pi-\alpha) \quad (1)$$

Instantaneous current is distributed by:

$$i_r(t) = \begin{cases} \frac{V_m}{X_r}\left[\cos\left(\frac{\pi-\sigma}{2}\right) - \sin(\omega t)\right], & \frac{\pi-\sigma}{2} \le \omega t \le \frac{\pi+\sigma}{2} \\ 0, & \frac{\pi+\sigma}{2} \le \omega t \le \frac{3\pi-\sigma}{2} \end{cases} \quad (2)$$

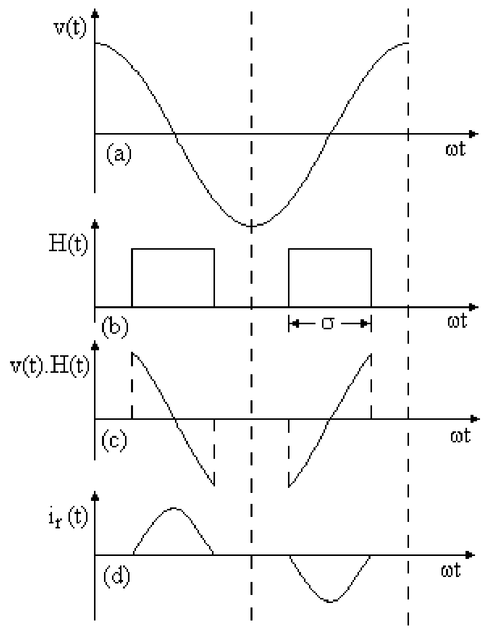

Figure 3. Voltage and current waveforms of TCR.

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Fourier analysis of the efficient current waveform provides the basic aspect:

$$I_{r1} = \frac{V_m}{\sqrt{2}.X_r}\left(\frac{\sigma - \sin\sigma}{\pi}\right) \quad (3)$$

wherever X_r could be the reactance of the reactor at basic frequency. The effect of increasing α (i.e., decreasing σ) is to reduce the essential portion I_1 [7].

Referring to Figure 3, the voltage over the terminals is thought to become a perfect sinusoidal waveform (Figure 3a). The existence function (Figure 3b) is twice the frequency of the voltage and it's based on the zero crossing of the voltage. Its width is the angle sigma(σ), the angle through which the current in a thyristor conducts. Multiplying the source voltage by the existence purpose picks up parts of the voltage curve. These parts are integrated to acquire the current through the controlled reactor (Figures 3c and 3d) [6]. The existence purpose H could be indicated as follow,

$$H(t) = \frac{\sigma}{\pi} + \sum_{h=1}^{\infty} \frac{2}{h\pi}\cos(h\pi)\sin(h\sigma)\cos(2h\omega t) \quad (4)$$

By taking into consideration the harmonic effects of static VAR compensator the equivalent circuit may be provided with as Figure 4 [6].

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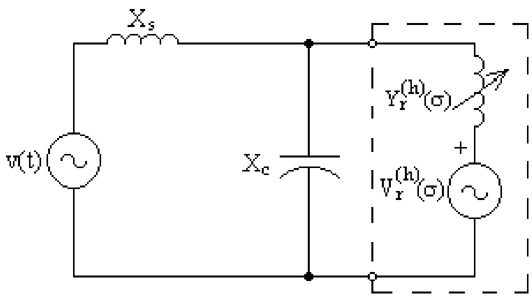

Figure 4. Variable voltage supply and admitance model for a TCR.

The reactor admitance based on thyristor conduction angle could be described the following:

$$Y_r^{(h)} = \frac{\sigma - \frac{\sin(h\sigma)}{h}}{hX_r\pi} \qquad (5)$$

In the circuit, harmonics components of the current and voltage respectively could be prepared as below,

$$V_r^{(h)} = \sqrt{2}.V_m.\cos(\frac{h-1}{2}\pi)\frac{1}{\sigma - \frac{\sin(h\sigma)}{h}} \times \left[\frac{\sin(\frac{h+1}{2}\sigma)}{h+1} - \frac{\sin(\frac{h-1}{2}\sigma)}{h-1}\right] \qquad (6)$$

$$I_r^{(h)} = V_r^{(h)}.Y_r^{(h)} \qquad (7)$$

wherever the current and the voltage contain only odd harmonics, and the amplitudes would be the functions of the conduction angle [6].

TCRs cause different harmonics issues by acting a nonlinear load. Harmonics happen due to the phase control in a TCR. The voltage of the reactor contain different harmonics and fundamental component of the reactor current be determined by chosen firing angle (α) or conduction angle (σ).

For the situation of balanced loading TCR creates odd harmonics. In a three phase system where in fact the TCR's are Δ-connected there will be no triplet harmonics injected into the power system [8]. However, TCR circuits shouldn't be operated on the points linked to resonance situations doing efficient harmonic production.

3. Stability and Harmonic

It's essential to pay attention to energy system stability in the planning, administration, and control of electrical power system for a more reliable and quality energy [9]. Stability in an energy system is an ability turning to the first operating problem following a distortion effect [10]. In voltage stability, the amplitude values of the load bus voltages of the system must be kept in a determined limit values in both steady-state and transient conditions.

If there is an uncontrollable and more and more reduction in voltage because of the the increase in load demand or a change in the system condition, it occurs voltage instability in the system. The main reason for instability is insufficient condition of power system corresponding to the need of reactive power. To be able to avoid the inadequate situation, it is an advantage to use the static VAR compensator including TCR [11].

Due to applying power electronics to do static VAR compensation cause instability in the power system on some operating conditions. When we do analysis in the problem of stability, the conditions creating instability are noticed to be on resonance conditions.

The high harmonic happened occurred in the system in the special conditions may cause compensation capacitors to resonance with other components' inductance in the circuits. The analysis of the system must be done by deciding the working condition producing instability.

Based upon the AC system impedance, the harmonic current injected into the system might distort the bus voltage. This distortion might demonstrate embarrassing as it may be possible to lose control of conduction angle of the TCR [4]. The distortions are described as complete harmonic distortion (THD) for current,

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \qquad (8)$$

Resonance problem for hth harmonic aspect is written by [12]:

$$\frac{X_{sh}.X_{rh}}{X_{sh} + X_{rh}} = X_{ch} \qquad (9)$$

wherever X_{ch}, X_{sh} and X_{rh} are hth harmonic component of capacitor reactance, nth harmonic certainly one of the system reactance and nth harmonic one of TCR reactance, respectively. In the power systems with TCR, general block diagram for resonance analysis is provided in Figure 5.

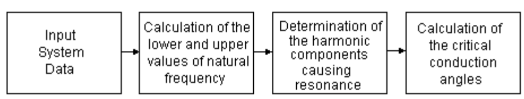

Figure 5. Basic block diagram for computation the critical conduction angles creating resonance.

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4. Numerical Application

To be able to determine the operating situations of TCR, a numerical analysis is done using figure 3 sample system. The values in the applying as per-unit has been taken; voltage V_c = 1.0 pu, reactance of TCR X_r=0.6 pu, fixed-capacitor reactance X_c = 2.0 pu, system reactance X_s = 0.082 pu and basic frequency 50 Hz (Base power is 1 MVA and base voltage is 1kV). The results from our software the following: For the conduction angle (σ) is between 30° and 38°, system is going to be in resonance at 5th harmonic component. Therefore, 80°, 120°, 160° is selected for the analysis. A harmonic current aspect value of TCR is provided in Table 1.

Table 1. Harmonic current aspect values.

Harmonic order (h)	$I_r^{(h)}(80°)$ (pu)	$I_r^{(h)}(120°)$ (pu)	$I_r^{(h)}(160°)$ (pu)
5	0.0345	0.0325	0.0458
7	0.0069	0.0116	0.0287

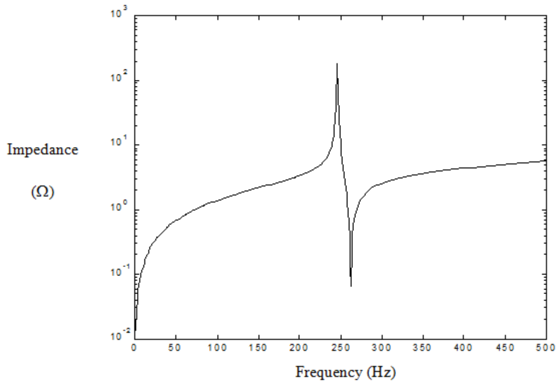

Figure 6. Impedance as function of frequency.

The validate the outcome of the prior analysis, the stability analysis was executed by utilizing MATLAB-Simulink program. The frequency analysis of the circuit shown in Figure 4 was prepared for 0-500 Hz range. The Bode diagram received from this analysis is revealed in Figure 6. As shown in Figure 4, there is a resonance occasion in the system due to the the fifth harmonic aspect (the critical frequencies are between 243-265 Hz range). The improvements of the current, match fundamental and harmonic parts for all conduction angles, are revealed in Figure 7 and 8, respectively.

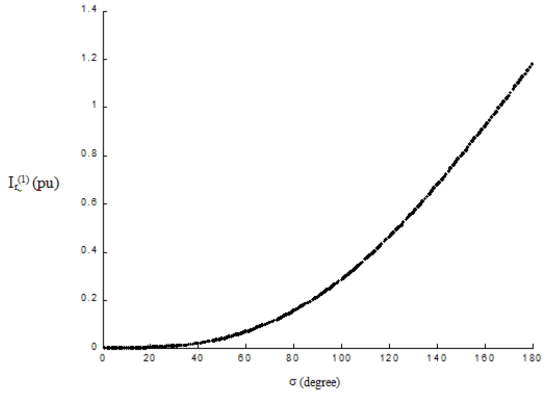

Figure 7. Basic current aspect versus conduction angle (σ).

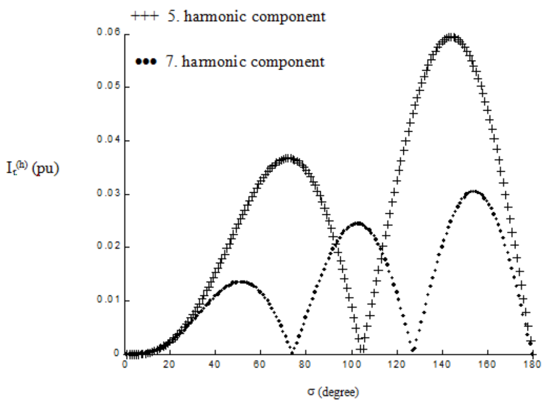

Figure 8. Harmonic current parts versus conduction angle (σ).

The current values of basic aspect and the full total harmonic distortion owned by the current for 80°, 120°, 160° in the system receive in Table 2.

Table 2. The current values of basic aspect and the total harmonic distortion values owned by the present in the system.

σ, conduction angle (degree)	$I_r^{(1)}$ (pu)	% THD $_{I_r}$
80	0.1544	22.78
120	0.4608	7.4863
160	0.9193	5.8749

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The change of the sum total current harmonic distortion for all conduction angles are shown in Figure 9. Equivalent suseptance is determined as in eq. (10) by utilizing capacitor reactance of FC-TCR.

$$B^{(h)}(\sigma) = Y_r^{(h)}(\sigma) - \frac{1}{X_c^{(h)}} \qquad (10)$$

Reactive power changes the following,

$$Q(\sigma) = B^{(h)}.(\frac{V_c}{\sqrt{2}})^2 \qquad (11)$$

The presence of 5th and 7th harmonics in the circuit, the deviation of reactive power for several conduction angles is revealed in Figure 10.

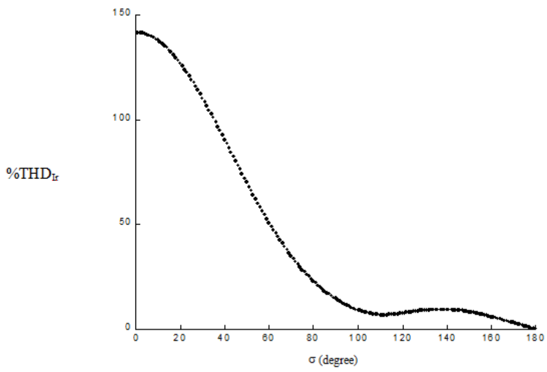

Figure 9. THD_{I_r} **versus conduction angle (σ).**

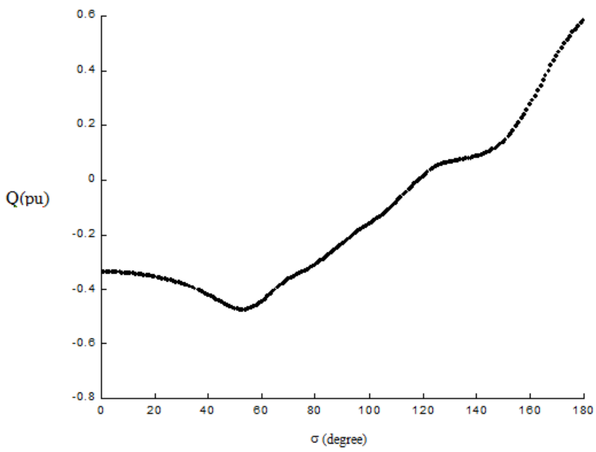

Figure 10. The modifications of reactive power

for several conduction angles.

In this specific example, the system is operated as inductive when conduction angles are between 0° and 120°, except for these situations; the system is operated as capacitive.

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5. Conclusion

These results could be based on this study for the system with static compensator including TCR:

The analysis effects show there are substantial harmonic distortions within the compensator system. The waveform distortions in the network are low in correctly developed the static compensator systems. In this study, the conduction angles must be chosen higher than 100° for the minimum overall harmonic distortion.

The RMS current is essential for operating value of static VAR compensator. The RMS current computation contains not only the basic part of the RMS current, but additionally the harmonic components.

When harmonic components aren't regarded, it's no probable to complete compensation accurately. It is needed to be changed the conduction angle for ideal reactive power.

If the harmonic components cause resonance functions in the system, the system will soon be instable. The determination of conduction angles which cause instable operation is very important for steady-state case. This event must be considered while the systems are made and operated.

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